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Startup of an Electrodeless RF Discharge in a Toroidal System in Presence of a Low Magnetic Field for Hydrogen

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ABSTRACT

Breakdown threshold voltage of an electrode less toroidal discharge has been studied using H- type solenoid coil excited by a 13.56 MHz radio frequency power in absence and in presence of a pre ionizing condition with different pressures, aspect ratio, and axial magnetic field for hydrogen. The breakdown threshold depends on various filling parameters e.g. pre-ionising condition, aspect ratio and magnetic field.

Key words: *Break down threshold, Toroidal discharge, H-type solenoidal coil, pre-ionising condition.*

1. Introduction

The present work is motivated by several issues related to the start-up phase of a toroidal discharge device like a tokamak, before setting up of the rotational transform. This phase consumes a sizable fraction of available flux swing (volt-second). In a typical fusion machine the parameters are rigid and cannot be varied beyond a narrow band of parameters, and the optimal start-up condition in a wide parameter space is basically unexplored. This work uses a set of simple and easy to make torii. Many such torii can be used with wide variation in all geometrical parameters [major radius (R), minor radius(r) and the aspect ratios (σ =R/r)].Working gases, pressure and magnetic field can also be varied within the available limits. It is hoped that this set of experiment will answer to several questions relating to the start-up phase of tokamak machine. A modelling of the start-up phase of a tokamak discharge was performed by Papoular [1] in which an analysis was made of the breakdown and ionisation of the filling gas in Toroidal devices like TA 2000 and TFR tokamak when it has been shown that the discharge can be developed. However the domain of discharge phenomenon was limited in the areas like the different types of gases and torii used. The purpose of our work is to expand the observation space and to draw the possible logical conclusion. However, the present communication provides results of the initial investigations.

Whether a discharge will develop depends on many factors[2,3]. In the overall picture it is evident that discharge depends on the competition between the processes that generates ionising electrons and the loss mechanisms. The pressure of the gas affects the electrons to pick up energy from the electric field due to collision with ions and other electrons. This phenomenon happens in straight and simple way in the DC field but takes place in a more complicated manner for an RF field. Gas pressure also controls the diffusion losses since it invariably helps to restrict perpendicular diffusion of charged particles to the wall of the torus. Then there is a host of atomic parameters which come into play even in a simplified model of the start-up phase of a toroidal machine and for the development of discharge in a toroidal machine [1,2,3,4].

2. Experiment

2.1 Experimental Setup

The experiment was performed in several pyrex glass toroidal chambers with varying geometric parameters. Here the results of five such chambers named as A, B, C, E and F with aspect ratio varying from 2.10 to 4.14 are presented [Table 1]. Each torus has its own pumping port, gas inlet and a pre-ionisation window. The chambers are mobile and can be mounted on the same experimental table and pumped by the same pumping system, here in this case, an oil diffusion pump backed by a rotary pump.

Table 1: The Characteristics Parameters of Different Torii

Torus	Minor radius (r) in m	Major radius (R) in m	Minor circum ference (2πr) in m	Length (l) of RF coil in m	Length (l) of RF coil in cm
A	0.0318	0.1318	0.1999	0.01498854	1.498854
E	0.0254	0.1004	0.1597	0.01398778	1.398778
C	0.0280	0.0792	0.1760	0.00999236	0.999236
B	0.0477	0.1000	0.2998	0.01448816	1.448816

The rf coils were mounted on each chamber. They consist of four parallel connected and inductively coupled coils, with same number of turns and wound at equal intervals around the torus. A fifth parallel coil of 28 gauge copper wire of hundred turns is wound around a chamber for primary tuned circuit.

The geometry of the torus and the position of the field windings are shown in Fig.1.

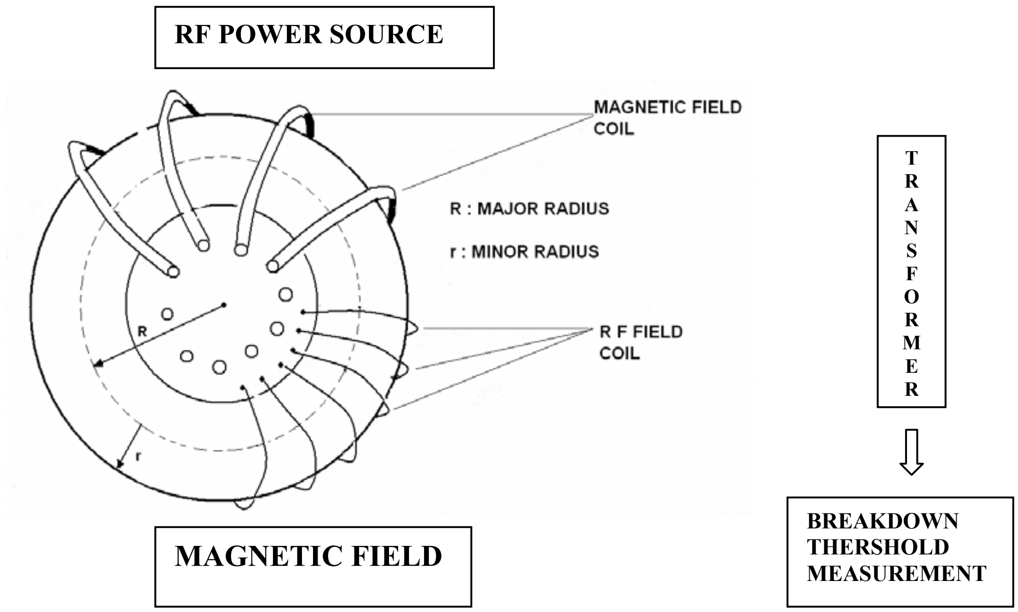

Figure :1 The Schematic Diagram Of The Experimental Set Up

2.2 Experimental Procedure

Our primary objective for the experiment and the analysis of the data obtained is to get a trend of the variation of different parameters concerned.

Initially the Toroidal chamber is evacuated to about 10^{-5} torr and was filled with hydrogen at different pressures varying from 0.001 to 0.1 torr. The pressure was measured with a pirani gauge.

An axial magnetic field was supplied and was varied from 0 G to 80 G. for a constant value of magnetic field, the pressure is raised and the breakdown voltage is determined.

The experiment was carried out under the following two cases:-

Case 1: The threshold breakdown voltage was varied with magnetic field for different pressures with or without pre-ionising effect for hydrogen in a toroidal chamber.

Case 2: The threshold breakdown voltage was varied with magnetic field for different torii with or without pre –ionising effect for hydrogen at a constant filling pressure of 0.1 Torr.

3. Results

The variation of threshold breakdown voltage with low magnetic field is quite predictable in the sense that with increasing of the magnetic field, plasma develops at a lower energy and the variation is almost linear. Hydrogen shows the linear nature of variation that breakdown voltage increases with increase in pressure and also it is to be noted that decrease in gas pressure also reduces the breakdown threshold voltage for plasma production within a torus. Presence of pre-ionisation within a torus definitely reduces threshold breakdown voltage.

It is also observed that the variation of threshold breakdown voltage with low magnetic field is almost linear (FIG. 2 & 3).

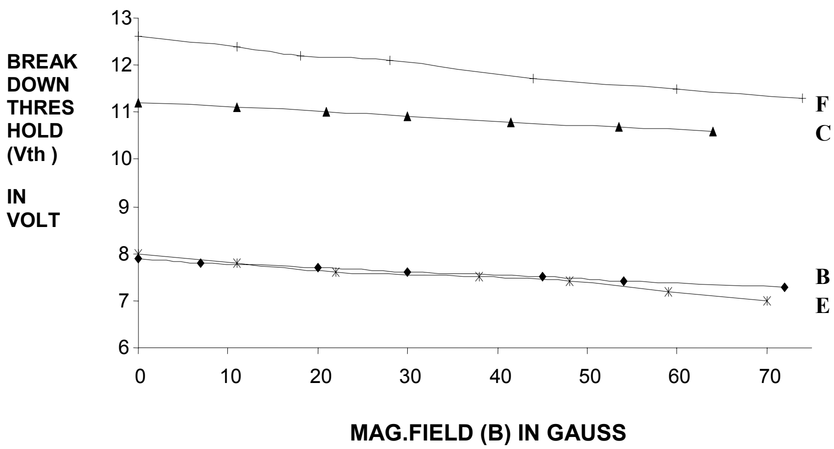

FIGURE 2: Variation of breakdown threshold voltage with magnetic field at a constant pressure of 0.1 torr for different torii with pre ionisation condition for hydrogen

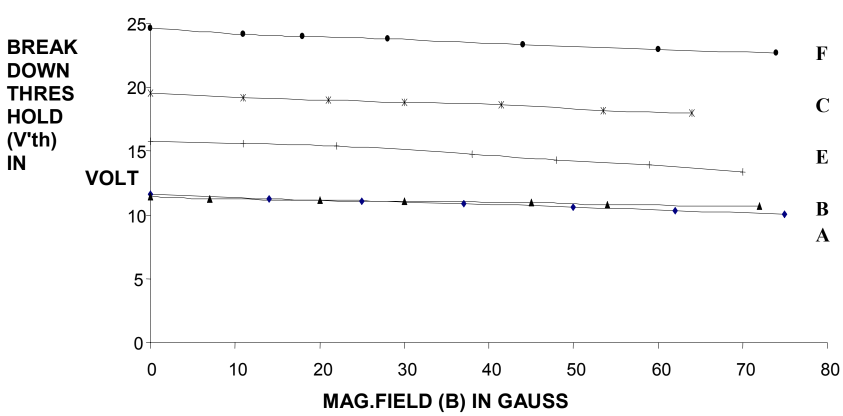

FIGURE 3: Variation of breakdown threshold voltage with magnetic field at a constant pressure of 0.1 torr for different torii without pre ionisation condition for hydrogen

4. Discussions

4.1 The Breakdown Mechanism

The competing mechanism in the process of breakdown are here, on one hand, ionisation by electrons accelerated in the induced electric field E, and, on the other hand, loss of electrons to the chamber walls through diffusion or drift, and loss by attachment or recombination[1,4].

4.1.1 Ionisation

Since the initial free electron density is small (weak pre ionisation), the best model to be used here presumably is the Townsend avalanche. In this model, the average free electrons are considered to acquire, after a few collisions, a constant Drift Velocity (V_d), which is a function of E/P, where P is the gas pressure and $V_d \parallel E$. In this motion, the electron produces, on the average α ionisations per m path, where α is the Townsend's first coefficient, also an increasing function of E/P. Together with its directed motion, the free electron also has a random motion ,which for not too large E/P, may be characterised by electron temperature (T_e).We shall take for Hydrogen for two torii (namely A and C) having different aspect ratios.

Townsend's first ionization coefficient (**α**) is defined as the number of ions produced by the electron per cm in the direction of the field. The value of (**α**) depends upon the pressure (**P**) and the field (**E**).

$$\alpha / P = \mathcal{A} \exp[-\mathcal{B} / (E / P)] \quad (1)$$

where **P** is the pressure

$\mathcal{A} = 1/L$ (**L** is the mean free path of the electron in the gas at a pressure of 1mm of mercury)

$\mathcal{B} = V_i / P$ (V_i is the ionization potential of the gas)[Table 2]

The variation of **α / P** with **E/P** for different torii is shown in Figure 3 and figure 4.

Table 2: The Values Of $\mathcal{A}$ & $\mathcal{B}$ For Hydrogen

Gas	$\mathcal{A}$ in 1/cm torr	$\mathcal{B}$ in volts /cm torr	Mean free path (L) in cm
Hydrogen	5.4	139	0.1852

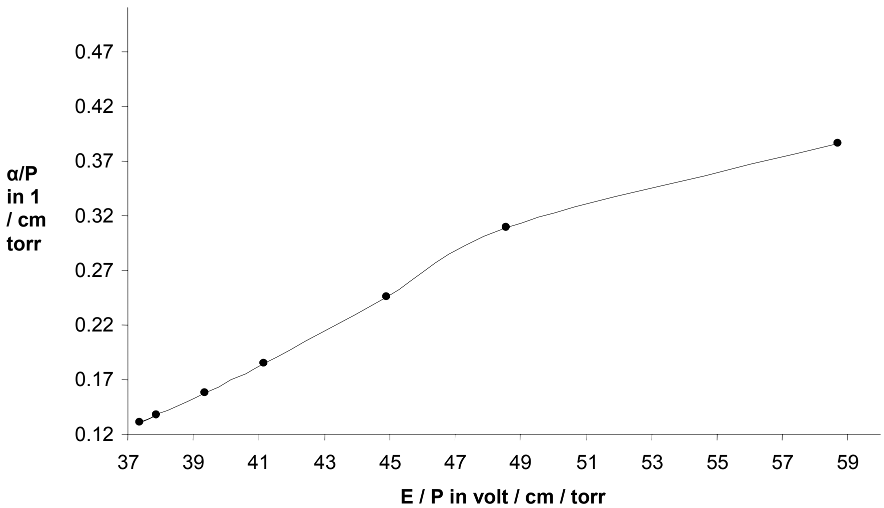

Figure 3: Variation of α/P with E /P for Torus A with Hydrogen gas

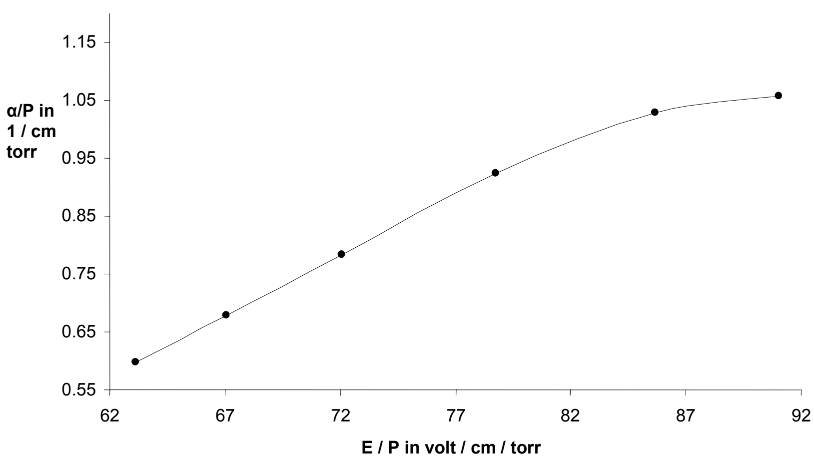

Figure 4: Variation of α / P with E / P for Torus C with Hydrogen gas

4.1.2 The Parallel Drift Velocity

The drift velocity $V_d = eL/mV_r (E/P)$ (2)
Where e is the charge of an electron (1.602 X 10^{-19} coulomb)

m is the mass of an electron (9.1 X 10^{-28} gms) or (9.1 X 10^{-31} Kg)
L is the mean free path of an electron of the corresponding gas at a pressure of 1 mm of Mercury
V_r is the random velocity of an electron
E is the applied electric field
P is the filling pressure within the torus
Again $1/2\, mV_r^2 = 1/2\, KT$ (3)
where K is the Boltzmann Constant (1.380 X 10^{-23} Joules/ ^{0}K) or (8.617 X 10^{-5} eV/ ^{0}K) and T is the room temperature in ^{0}K
Therefore $V_r = (KT/m)^{1/2}$ (4)
Using equations 2, 3 and 4
The drift velocity becomes
$V_d = eL/(mKT)^{1/2}\, (E/P)$ (5)
and the ionization rate (υ) becomes [4]
$\upsilon = \alpha V_d$
$= \alpha\, eL/(mKT)^{1/2}\, (E/P)$ (6)
where α is the Townsend's first ionization coefficient

4.1.3 The Diffusion Loss

The diffusion loses can be expressed as uniform rates (per second), per electron. In a confined plasma there will be generally a density or pressure gradient from the interior to the outside which will cause charged particles to diffuse and eventually escape to the walls of the torus. As the motion of electrons and ions are affected by a magnetic field, it is natural that the diffusion of electrons and ions change by the application of the magnetic field. Diffusion of electron due to elastic collision with molecules in presence of magnetic field is characterized by the coefficient [1,4]
$D_H = D / (1+ \omega_H{}^2 \tau^2)$ (7)
where D is the diffusion coefficient in absence of magnetic field [4]
Now $D = 1/3\, V_r \lambda_e$ (8)
where V_r is the random velocity of an electron and λ_e is the mean free path of an electron
$\lambda_e = L/P$ (9)
$\omega_H = eH/m$ (10)
where H is the toroidal field in Gauss
τ is the time between successive collisions between the electron and the neutral gas molecules known as mean free time
$\tau = \lambda_e / V_r$
$= L / P\, V_r$ (11)
$D_H = (1/3\, V_r L/P)/(e^2H^2/m^2 . L^2/P^2\, V_r{}^2)$
$D_H = Pm^2/ 3Le^2H^2\, (KT/m)^{3/2}$ (12)
Diffusion loss rate = D_H / r^2 [1]
where r is the minor torus radius
The variation of diffusion loss rate with magnetic field at a constant pressure and with pressure at a constant magnetic field in different torii is shown in Fig.5 and Fig.6.

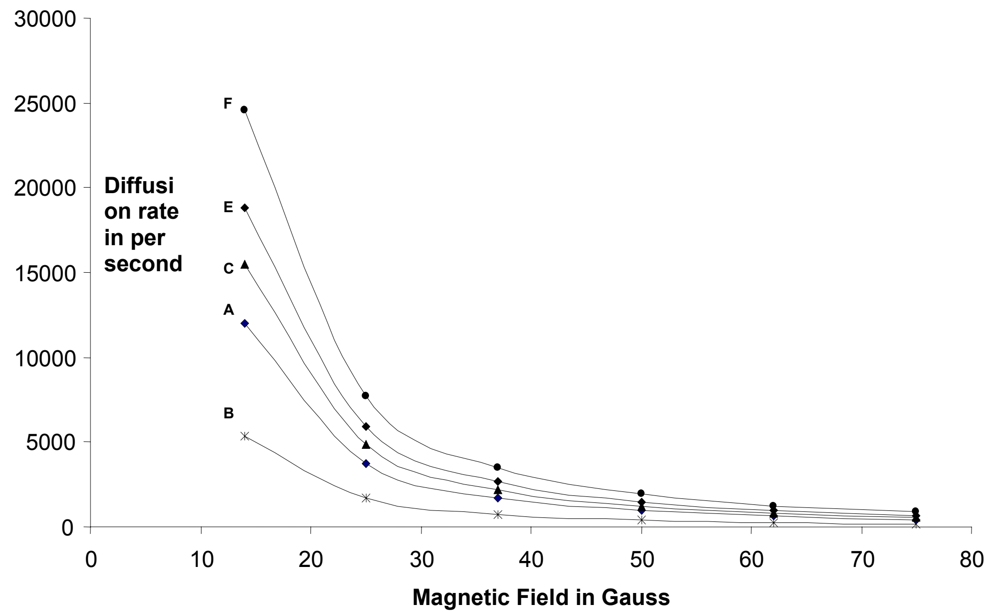

FIGURE 5: Variation of diffusion loss rate with magnetic field in different torii .

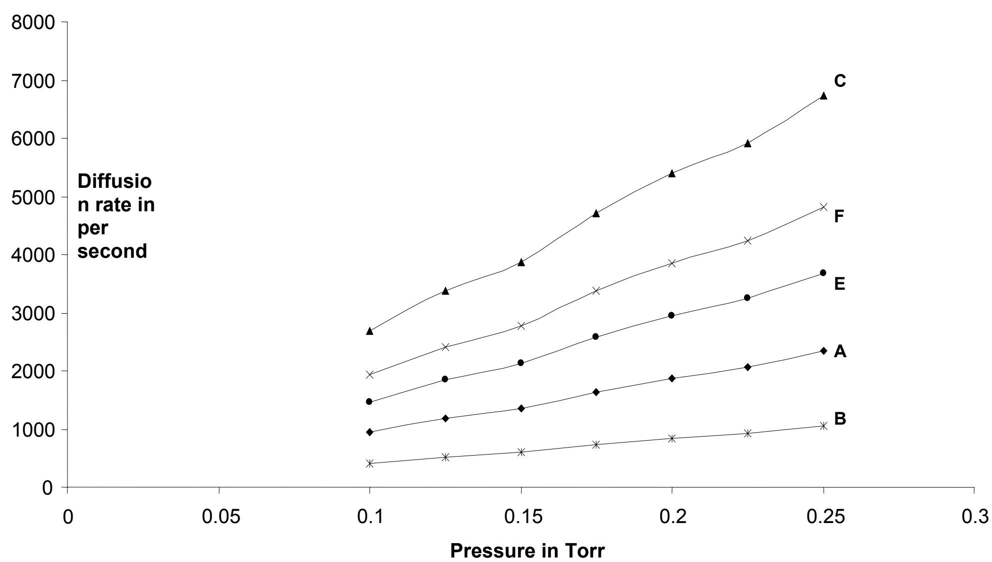

FIGURE 6 : Variation of diffusion loss rate with pressure at a constant magnetic field of 50 gauss in different torii.

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